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A Method to Further Reduce the Perceived Noise of Low Tip Speed Fans

James H. Dittmar
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A Method to Further Reduce the Perceived Noise of Low Tip Speed Fans

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A METHOD TO FURTHER REDUCE THE PERCEIVED NOISE OF LOW TIP SPEED FANS

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ABSTRACT

The use of low tip speed, high bypass ratio fans is a method for reducing the noise of turbofan jet engines. These fans typically have a low number of rotor blades and a number of stator vanes sufficient to achieve cut-off of the blade passing tone. Their perceived noise levels are typically dominated by broadband noise caused by the rotor wake turbulence - stator interaction mechanism.

A 106 bladed, 1100 ft/sec takeoff tip speed fan, the Alternative Low Noise Fan, has been tested and shown to have reduced broadband noise. This reduced noise is believed to be the result of the high rotor blade number. Although this fan with 106 blades would not be practical with materials as they exist today, a fan with 50 or so blades could be practically realized. A noise estimate has indicated that such a 50 bladed, low tip speed fan could be 2 to 3 EPNdB quieter than an 18 bladed fan. If achieved, this level of noise reduction would be significant and points to the use of a high blade number, low tip speed fan as a possible configuration for reduced fan noise.

INTRODUCTION

The use of low tip speed, high bypass ratio fans is a method to reduce the noise of turbofan jet engines. At high tip speeds the tone noise dominates the perceived noise levels. As the tip speed is lowered the noise of the fan is reduced and the relative strengths of the tone and broadband noise sources is changed such that the broadband noise becomes more important. For example, the Pratt & Whitney Advanced Ducted Propulsor - Fan 1 tested at Glenn Research Center, reference 1, had its perceived noise dominated by the broadband component. A previous paper, reference 2, indicated that the broadband noise from the rotor wake turbulence-stator interaction mechanism could be reduced by using a low number of long chord stator vanes. Even though this low number of stator vanes allowed for a cut-on and therefore louder blade passing tone, the net perceived noise was reduced because the dominant broadband noise source was reduced. Recent testing of the Alternative Low Noise Fan has shown that even further reductions in the rotor wake turbulence-stator interaction noise may be possible. This paper presents some of the results from the Alternative Low Noise Fan testing and indicates that a different fan design could further lower broadband noise and result in lower perceived noise.

ALTERNATIVE LOW NOISE FAN

Background

The conventional method for reducing fan noise has been to go to a low tip speed, high bypass ratio fan. This fan would have a low number of rotor blades with the number of stator vanes selected to provide for cut-off of the blade passing tone. In references 3 and 4 an alternative method was proposed to reduce the perceived noise of the fan tones. In reference 3, for a 6 foot diameter fan, the method used a high number of rotor blades to shift the higher harmonic tones to frequencies above the perceived noise rating range leaving only the blade passing tone to be rated. A 106 bladed fan at 1100 ft/sec tip speed was investigated. This fan would have its blade passing tone at 6,000 hertz, with twice blade passing at 12,000 hertz which is above the rated range. The concept further included a small number of long chord stator vanes to reduce the rated blade passing tone. The Alternative Low Noise Fan was predicted to give approximately the same noise level as the conventional low tip speed fan approach.

Apparatus and Procedure

To investigate this concept a 0.305 scale fan model, 22 inches in diameter, of the Alternative Low Noise Fan (ALNF) was built and tested in the Glenn 9 x 15 foot Low Speed Wind Tunnel. This fan was designed with 106 rotor blades and 14 long chord stator vanes to be the alternative approach to a conventional low tip speed, low rotor blade number, cut-off fan such as the Allison Engine Company model fan also tested in the 9 x 15 wind tunnel (reference 5). To examine the noise reduction achieved by the low number of long chord stators a more conventional 70 vane stator was also tested. Table I includes some of the details of the ALNF design.

Cross section drawings of the ALNF with 14 and 70 stator vanes are found in figure 1, part a and b respectively. These drawings are for the configurations which included acoustic treatment on the flow passage walls. Hard wall configurations were also tested by replacing the acoustic treatment pieces with smooth wall pieces having the same flow path contours. All of the data presented in this report are from the hard wall configuration. A photograph of the fan being tested in the wind tunnel is shown in figure 2. The acoustic treatment on the wind tunnel wall is shown in this photograph along with a traversing microphone used to acquire noise data. A photograph of the 106 bladed fan rotor is shown in figure 3. A photograph of the 14 vane stator is found in figure 4 and the 70 vane stator is shown in figure 5. During the initial part of the testing with the acoustically treated nacelle, the fan flow was limited by internal flow problems. In an attempt to obtain the proper flow rate, every other one of the 14 stators was removed resulting in a 7 vane configuration. A photograph of this 7 vane stator configuration is found in figure 6. The proper flows were obtained for both the 7 and 70 vane configurations in the hardwall nacelle configuration indicating that in some way the acoustic treatment was the cause of the flow problems. The acoustic data from these hard wall configurations are used in this report. These acoustic data were obtained by both a traversing microphone and fixed microphones install in the wind tunnel. A top view sketch of the tunnel showing the traversing and fixed microphones is shown in figure 7.

Acoustic Results

The purpose of the test was to determine if the Alternative Low Noise Fan would have a rated noise equivalent to a conventional low tip speed fan. Therefore comparisons with the Allison Engine Company fan, reference 5, were intended. A photograph and a cross section of the Allison fan in the straight bladed close stator position, which was the comparison configuration, are shown in figure 8. The primary comparisons were to be made at the takeoff condition which was at 1100 ft/sec for the ALNF and 840 ft/sec for the Allison fan. However, during testing of the ALNF, the rotor blades encountered a high stress region at speeds higher than 1000 ft/sec tip speed which precluded remaining at the higher speeds for a period long enough to obtain acoustic data. Therefore the 1000 ft/sec condition is the highest speed at which acoustic data was obtained for the hard wall ALNF testing. At this 1,000 ft/sec tip speed the ALNF produced a fan stage pressure ratio of 1.24 compared with the 1.27 pressure ratio of the Allison Fan at takeoff. Assuming the noise would vary with 10 log of the thrust, the pressure rise ratio of 0.27 / 0.24 would result in approximately a 0.5 dB correction that should be added to the 1000 ft/sec ALNF data for comparison with the Allison data. For most of the direct spectrum to spectrum comparisons of the two fans this 0.5 dB is not significant and is not included on the plots. It is, however, included in the effective perceived noise comparisons that will follow.

A comparison between the 7 vane stator ALNF at 1,000 ft/sec tip speed and the Allison fan at 840 ft/sec tip speed is shown in figure 9. Here narrowband spectra from 0 to 50,000 hertz with a bandwidth of 59 hertz are shown at the 3 emitted angles of 25, 90 and 128 degrees from the fan inlet axis. These are parts a , b and c of figure 9 respectively. The data are presented as 1 foot lossless data. These data are shown as they were taken on the 22 inch diameter model. Therefore the frequencies are higher than they would be for the 6 foot diameter full scale fan. For example, looking at figure 9 b at 90 degrees, the ALNF blade passing tone is apparent around 18,000 hertz and the tone at twice blade passing frequency is just visible near 36,000 hertz. On the 6 foot diameter fan these would be about 5,000 and 11,000 hertz. On this figure the blade passing tone for the Allison fan would be around 2,750 hertz but since it is cut-off it is not visible in the spectra. Tones at twice blade passing frequency, 5,500 hertz and four times blade passing frequency 11,000 hertz are clearly visible and the tone at 3 times blade passing frequency, around 8,250, can be seen above the background. These would be lower on the full scale fan with blade passing frequency being around 840 hertz, 2bpf at 1680 hertz, 3bpf at 2520 and 4bpf at 3360 hertz.

As can be seen by looking at figure 9, not only has the ALNF achieved its goal of being as quiet as the Allison fan but it appears even quieter. The tone levels of the ALNF would have a lower perceived noise rating than the tones of the Allison fan not only because of the frequency shift to the lower rated regions of the spectra as indicated by reference 3 but also because the levels themselves are lower. As can be seen again in figure 9, the blade passing tone sound pressure level of the ALNF is lower than that of the 2 times blade passing frequency tone of the Allison fan and is about the same level as the 3 times blade passing frequency tone. Therefore the perceived noise of the tones for the ALNF will be lower than the perceived noise of the tones for the Allison fan.

Possibly more interesting , however, is the broadband noise reduction apparent in the spectra. The ALNF appears to have lower broadband noise over a frequency range from about 2,000 hertz to 16,000 hertz. Some multiple pure tone activity is adding to the ALNF noise at the lower frequencies at the aft angles but even there it is just coming up to the (Figure 9b) or slightly above (figure 9c) the Allison broadband noise level. On the full scale fan the broadband noise reduction would be from about 600 to 5,000 hertz for the 6 foot diameter fan. This broadband reduction would have an even larger noise reduction effect on the perceived noise than would the lower tones.

The magnitude of the effect of the broadband noise reduction can be better observed in 1/3rd octave spectra as used by the perceived noise rating method. Figure 10 parts a, b, and c shows the 1/3rd octave spectra for the 25, 90 and 128 degree angles respectively. When viewed on the 1/3rd octave basis, the broadband noise reduction becomes even more evident. Now instead of just having a noise reduction at the design 6 foot or smaller diameter because of the tone shift, this broadband noise reduction would result in perceived noise reductions at most reasonable fan sizes.

An indication of this perceived noise reduction can be seen in figure 11. Here the Effective Perceived Noise for a single fan flyover at 1000 ft altitude on a standard day has been calculated for the Allison fan and the ALNF at scale factors ranging from 2 to 6. Here the EPNdB of the ALNF has been increased by 0.5 dB to account for the lower pressure ratio. The scale factor is the number that the 22 inch diameter fan would be multiplied by to obtain the full scale diameter. For example, the 6 foot diameter fan would be at a scale factor of approximately 3.27.

As can be seen the ALNF is significantly quieter at all of the scale factors shown. As the scale factor increases the two fans start to come closer together in level. This is because the frequency shift of the larger scale has brought the higher frequencies of the model data, where the two fans have the same levels(20,000 hertz and above, figure 10), down into the most highly rated range of the EPNdB calculation.

The reason behind this broadband noise reduction can be inferred from looking at comparisons between the 70 and 7 vane ALNF data and by examining the geometry of the ALNF fan. Previous work has been done on the effect of stator vane number on the broadband noise generated by rotor wake turbulence-stator interaction (reference 6). This work indicated that the noise was reduced with lower stator vane numbers, varying approximately as 10 times the log of the ratio of the stator vane numbers. Therefore it would be expected that in going from 70 to 7 vanes that the broadband noise would be reduced about 10 dB.

For the purposes of comparing the effect of stator vane number on the broadband noise of the ALNF a low tip speed case of 800 ft/sec tip speed was chosen so that the possible masking effect of the multiple pure tones would be minimized. Figure 12 shows the ALNF data for 70 and 7 vanes in the front at 25 degrees, part a, and in the back at 128 degrees, part b. In the front there is no effect of the vane number on the broadband noise and there is only a small 3 or so dB effect seen in the back.. In both cases much less than the expected 10 decibels. Significant reductions in the tone levels were obtained but not for the broadband noise. A probable explanation for this lack of broadband noise reduction is that the rotor wake turbulence - stator noise mechanism is no longer dominant for the ALNF fan. The possible reason for the reduction in the rotor wake turbulence - stator source on the ALNF and its implications for other fans will be discussed in the next section.

REDUCED BROADBAND NOISE

Possible Explanation for ALNF

Two possible explanations for the reduction in broadband noise of the ALNF will be explored in the following sections: 1. A reduced turbulence strength impacting the stator brought about by a reduction in the initially generated turbulence and an increased decay of this turbulence and 2. A shift in the turbulence to smaller length scales which result in reduced levels of low frequency noise. Both of these possible explanations can be related to the increased number of rotor blades. A possible reduction in the noise of a low tip speed fan by increased rotor blade number will be discussed.

Reduced Turbulence Level

The pressure rise of the ALNF is spread over 106 short chord blades while the Allison fan has the pressure rise provided by 18 larger chord blades. This provides lower loading per blade for the ALNF with less losses per blade. The result would then be smaller initial wake defects and lower initial turbulence for the ALNF. The following is an attempt to roughly estimate the level of the expected noise difference between the Allison fan and ALNF. This is intended to be only a rough, back of the envelope type of estimate and is not a detailed prediction of the noise difference between the two fans.

With less loading (lift) being needed for each blade of the ALNF, the drag on each blade would be less and the wake would be smaller. It is assumed here that the initial turbulence would also follow the same pattern being lower for more blades. As an approximation, the initial turbulence level for the ALNF is assumed to be 18/106 of the turbulence level for the Allison fan. When the turbulence interacts with the downstream stators it creates a fluctuating lift which in turn creates noise. This noise goes as 20 log of the lift fluctuation and it is assumed that the lift fluctuation goes directly with the turbulence level. Using this 20 log of the turbulence level, the lower initial turbulence of the ALNF would result in approximately a 15.4 dB reduction in the rotor wake turbulence- stator broadband noise source.

The wake defect behind a blade has been indicated as following a form such as

$$\frac{v}{V} \propto \frac{1.17543\left(X/C_r\right)+1.28626}{10.79857\left(X/C_r\right)+1.0} \text{(ref. 7).} \qquad (1)$$

where v is the maximum difference from the free stream velocity in the wake, V is the free stream velocity, X is the distance downstream from the trailing edge of the airfoil and C_r is the chord length. As can be seen, the wake decays with X/C_r. With a shorter chord for the 106 bladed fan, the same axial distance from the rotor trailing edge to the stator leading edge would have more decay of the wake for the ALNF than for the Allison fan. In the close position, the Allison fan had 4 inches between the rotor and stator while the ALNF was more closely spaced at 3.6 inches. However, in rotor chords, the Allison fan has a 1.2 chord spacing while the ALNF has 4.5. This would result in more decay of the turbulence for the ALNF than for the Allison fan. If the turbulence decays at the same rate as the wake defect, then a rough estimate of the difference between the Allison turbulence decay and the ALNF decay would then be that the ALNF would be 3.3 dB quieter. The summation of both the lower initial level and the additional decay would then be an expected broadband reduction of 18.7 dB.

To complete the rough estimate of the expected noise reduction between the ALNF and the Allison fan, the additional noise from the higher tip speed needs to be included. The ALNF would be expected to show a broadband noise increase because of its higher tip speed. In reference 8, the broadband noise and the overall sound power were shown to follow the same general correlation (figures 12 and 13 of reference 8) One form of this expression is found below (equation. 6 of reference 8).

$$PWL = k + 10 \log A + 50 \log U_t \text{ (ref. 8)} \tag{2}$$

Where A is the fan flow area, U_t is the tip speed and K is a constant depending on fan design parameters. Using this expression, the expected broadband noise increase of the ALNF because of its higher tip speed can be estimated from the 50 log U_t term. The tip speed ratio of 1000/840 would lead to an expected increase of approximately 3.8 dB. The net expected reduction in the ALNF broadband noise would then be around 14.9 dB. In looking at figure 10, the actual reduction is somewhat less, being in the 8 to 10 dB range for the maximum reduction. The fact that all of the 14.9 dB is not observed can probably be explained by the realization that the rotor wake turbulence - stator noise was reduced so much that it hit a noise level where some other broadband noise mechanism now controlled the level. A possibility for the now dominant broadband source might be the inlet boundary layer - rotor interaction mechanism. This reaching of a floor would be supported by figure 12 which shows little or no broadband noise reduction in going from 70 to 7 vanes when a 10 dB reduction in the rotor wake turbulence - stator broadband noise was expected.

Reduced Turbulence Length Scale

As a result of the increased number of rotor blades on the ALNF, the gap between blades is decreased. These smaller gaps do not permit as many of the large scale turbulence eddies to be generated. This can result in the reduction in the low frequency noise that these large scale eddies generate. Looking at this in another manner for a Liepmann type of turbulence spectra, the integral length scale for the ALNF would be much lower than that for the Allison fan. Hanson and Horan, reference 8, have indicated that at low frequencies these small length scales generate less noise. In figure 10 of reference 8, done for a 12 foot diameter fan, our scale factor of 6.5, significant noise reductions were observed at the low frequencies with smaller length scales.

Using the results of this figure 10 a rough estimate of the noise reduction from the smaller length scale of the ALNF can be made.

In figure 10 of reference 8, when going from the base length scale of 0.035 to a smaller length scale of 0.018 approximately a 7 dB noise reduction was obtained at 500 hertz. Using this 7 dB per halving of the length scale as a rough approximation, some estimates of the expected reduction in broadband noise can be made for the ALNF. If we assume the length scale varies with the gap size, which in turn goes as the inverse of the rotor blade number, the change in length scale from the Allison to the ALNF is 18/106. Using this ratio a 20.6 dB broadband noise reduction would be expected. On our 22 inch rig, at the 6.5 scale factor, this reduction would be expected to occur around 3250 hertz. Again the tip speed difference would have to be included, thereby adding 3.8 dB for an expected reduction of 16.8 dB. This number is within a couple of dB of the 14.9 dB estimated previously from the turbulence strength reduction. The rough estimate of this broadband noise reduction from the reduced length scale is again greater than the broadband noise reduction actually obtained. As mentioned previously, the fact that all of the expected reduction was not obtained may be that the noise level of the rotor turbulence - stator interaction noise may have been reduced so much that it is no longer the dominant source and a noise floor caused by some other mechanism may be present.

Possible Low Tip Speed Fan

The Alternative Low Noise Fan test has shown that broadband noise reduction is possible from increasing the number of rotor blades. The ALNF is a research fan designed to push the technology envelope. This 106 bladed fan would probably not be practical until new materials and processes were developed to enable these very thin blades to survive in an operational environment. At present a number of turbofan engines are flying with fan stages of 40 to 50 blades. These fan stages are typically at higher pressure ratios and tip speeds than the Allison fan so it is reasonable to assume that a 50 bladed low tip speed fan could be practical. Such a fan would combine the noise advantages of the low tip speed with the broadband noise reduction from the 50 rotor blades. A rough estimate of the noise reduction possible from the 50 bladed fan as compared with the 18 bladed Allison fan is now undertaken.

As indicated in a previous section, one of the possible explanations for the broadband noise reduction is that the large number of rotor blades spreads the load over more blades resulting in less loading per blade and lower levels of initial turbulence. The initial turbulence levels of a 50 bladed fan would be approximately 18 / 50 of the Allison fan for a noise reduction of approximately 8.9 dB. A further reduction would occur for the larger spacing to chord ratio. The solidity would be assumed the same as the 18 bladed Allison fan so the spacing to chord ratio would become 3.3. This then yields a further noise reduction of 2.7 dB for a total expected reduction of 11.6 dB. (No correction is applied for tip speed since the 50 bladed fan is assumed to have the same low tip speed as the Allison fan.)

Using the reduced turbulence length scale as the possible noise reduction mechanism, the 50 bladed fan would have the turbulence scale reduced by the ratio 18/50. This would result in an estimated reduction of 9.7 dB.

In referring to figure 11, the predicted noise reduction of the ALNF (14.9 for reduced turbulence level and 16.8 for the smaller length scale) resulted in only a 3 to 4 EPNdB reduction. This was because the observed peak noise reduction of about 8 to 10 dB was less than predicted because of a noise floor from other broadband noise sources had been reached and because the noise reductions were not seen for the entire frequency range. Since the predicted reductions for the 50 bladed fan, 11.6 for the turbulence level reduction estimate and 9.7 for reduced length scale estimate, are about the same as the observed 8 to 10 dB, it is possible that the broadband noise may come down to the same floor level giving a 3 to 4 EPNdB reduction. However, from a conservative viewpoint, a ratio might be more reasonable. Therefore a simple ratio is taken from the estimated broadband noise reductions. For the reduced turbulence level estimates, this is 11.6 for the 50 bladed fan versus 14.9 for the 106 bladed ALNF giving a ratio of 0.78. For the reduced length scale estimates, this is 9.7 dB for the 50 bladed and 16.8 for 106 bladed ALNF for a ratio of 0.58. When these ratios are applied to the observed 3 to 4 EPNdB reduction of the 106 bladed ALNF, the 50 bladed fan could have somewhere between 2.3 to 3.1 EPNdB reduction (turbulence level reduction method) or 1.7 to 2.4 EPNdB reduction (reduced length scale method) from the Allison fan. In general then both of the methods are showing that roughly 2 to 3 EPNdB noise reduction from the Allison fan may be possible for a low tip speed fan with 50 blades. This method of going to a high blade number fan to reduce rotor wake turbulence - stator interaction noise could show a significant perceived noise reduction for low tip speed fans.

CONCLUDING REMARKS

The use of low tip speed, high bypass ratio fans is a method for reducing the noise of turbofan jet engines. These fans typically have a low number of rotor blades and a number of stator vanes sufficient to achieve cut-off. These low tip speed fans appear to have their perceived noise levels dominated by broadband noise. This broadband noise has typically been dominated by the rotor wake turbulence - stator interaction mechanism. A 106 bladed, 1100 ft/sec takeoff tip speed fan, the Alternative Low Noise Fan (ALNF), has been tested in the NASA Glenn 9 x15 Foot Wind Tunnel. The results of this testing indicate that the broadband noise has been significantly reduced. The reduction in the rotor wake turbulence - stator interaction broadband noise may be the result of the large number of rotor blades. Two possible explanations for the noise reduction were investigated. The turbulence level may be reduced by the spreading of the rotor pressure rise among a large number of rotor blades may lower the initial turbulence level in the wake. In addition, the decay of this turbulence is believed to occur based on the distance downstream of the rotor measured in rotor chords. Therefore, with the same physical distance downstream more decay of the turbulence occurs for the large rotor blade number fan because its chord is shorter. The combination of the lower initial turbulence and its greater decay may have resulted in the broadband noise reduction. The noise reduction might also be explained by the reduced turbulence length scales of the ALNF generating less low frequency noise. There is even some evidence that the rotor wake turbulence- stator source has been reduced so much that it is no longer the dominant source mechanism, possibly being replaced by the inlet boundary layer - rotor mechanism. (A further reduction might then be accomplished by bleeding off the inlet boundary layer to reduce the boundary layer - rotor interaction noise.)

The 106 bladed ALNF is a research fan designed to push the technology level and as such it would probably not be a practical device with present materials technology. However, a fan with about 50 blades could be a practical device. Estimates of the noise of a low tip speed fan with 50 blades, done both with the reduced turbulence level method and the reduced length scale method, were compared with that of an 18 bladed low tip speed fan. A noise reduction of the order of 2 to 3 EPNdB was estimated. If achieved, this level of noise reduction would be significant and points to the use of a high blade number, low tip speed fan as a possible configuration for reducing fan noise.

REFERENCES

1. Dittmar,James H., et.al. Some Acoustic Results From the Pratt & Whitney Advanced Ducted Propulsor - Fan 1, NASA TM TBD, AST Paper AST011,1997.
2. Dittmar, James H., Reduced Perceived Noise For Low Tip Speed Fans As A Result of Abandoning Cutoff Stator Vane Numbers, NASA TM TBD, AST paper AST006, 1996.
3. Dittmar, James H. and Woodward, Richard P., An Evaluation of Some Alternative Approaches for Reducing Fan Tone Noise, NASA TM 105356, 1992
4. Dittmar, James H. , A concept for a Counterrotating Fan With Reduced Tone Noise, NASA TM 105736, 1992.
5. Woodward, Richard P. et. al. , Benefits of Swept and Leaned Stators for Fan Noise Reduction, NASA TM TBD, AST Paper AST018, 1997.
6. Ganz, Ulrich W., et al., Boeing 18 Inch Fan Rig Broadband Noise Test. NASA Contractor Report for NAS1-20090, task 4, 1997.
7. Topol, David A., and Philbrick, Daniel A., Fan Noise Prediction System Development: Wake Model Improvements and Code Evaluations. NASA Contract Report for Contyract NAS3-25952, April 1993.
8. Heidmann, M.F. and Feiler, Charles E., Noise Comparisons from Full-Scale Fan Tests at NASA Lewis Research Center. AIAA Paper 73-1017, Oct. 1973. (Also, NASA TM X-68289)
9. Hanson, Donald B. and Horan, Kelly., Turbulence/Cascade Interaction: Spectra of Inflow, Cascade Response, and Noise. AIAA Paper 98- Presented at the 4th AIAA/CEAS Aeroacoustics Conference,1998.

TABLE 1.—ALTERNATIVE LOW NOISE FAN MODEL

Fan diameter	22 in.
Takeoff pressure ratio	1.3
Takeoff tip speed	1100 ft./sec.
Rotor blade number	106
Stator vane number	14 long chord 70 short chord
Nacelle configurations	Hardwall Acoustic treatment

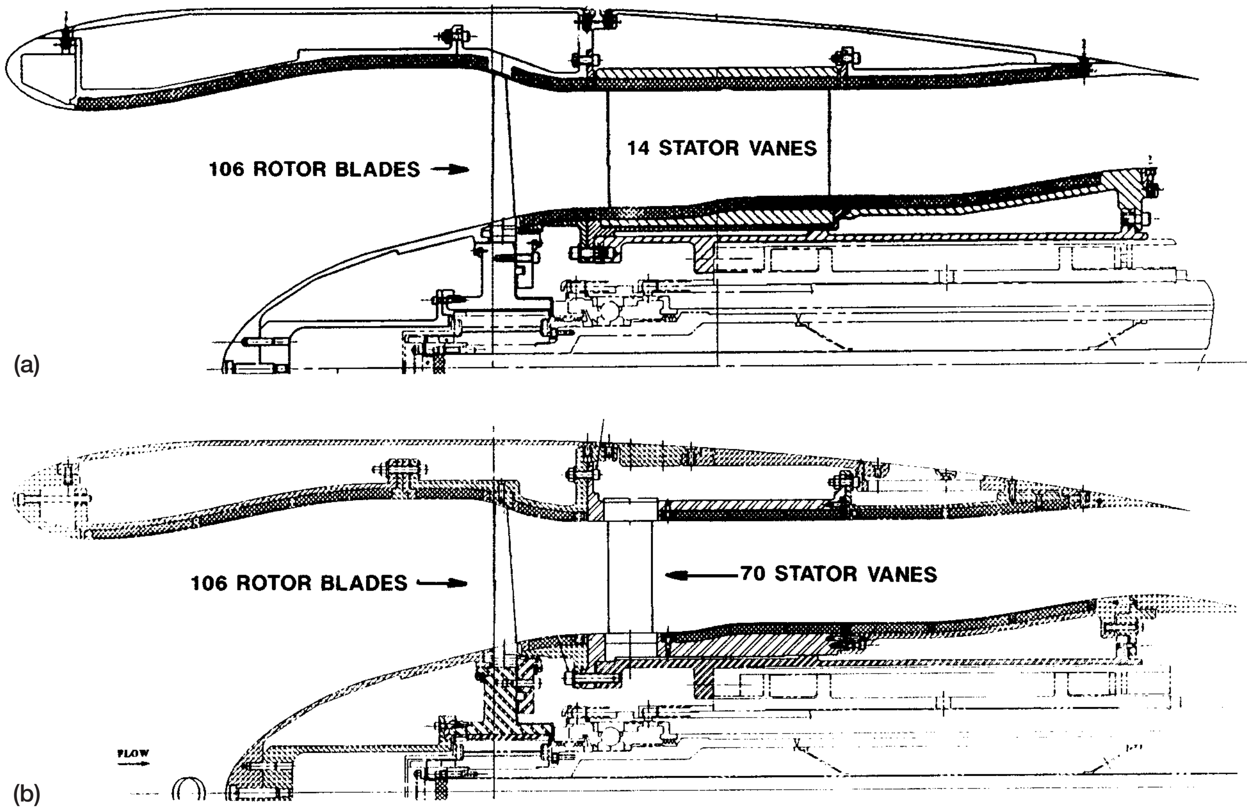


Figure 1.—Alternative low noise fan. (a) 14 vane stator. (b) 70 vane stator.

Figure 2.—Alternative low noise fan in wind tunnel.

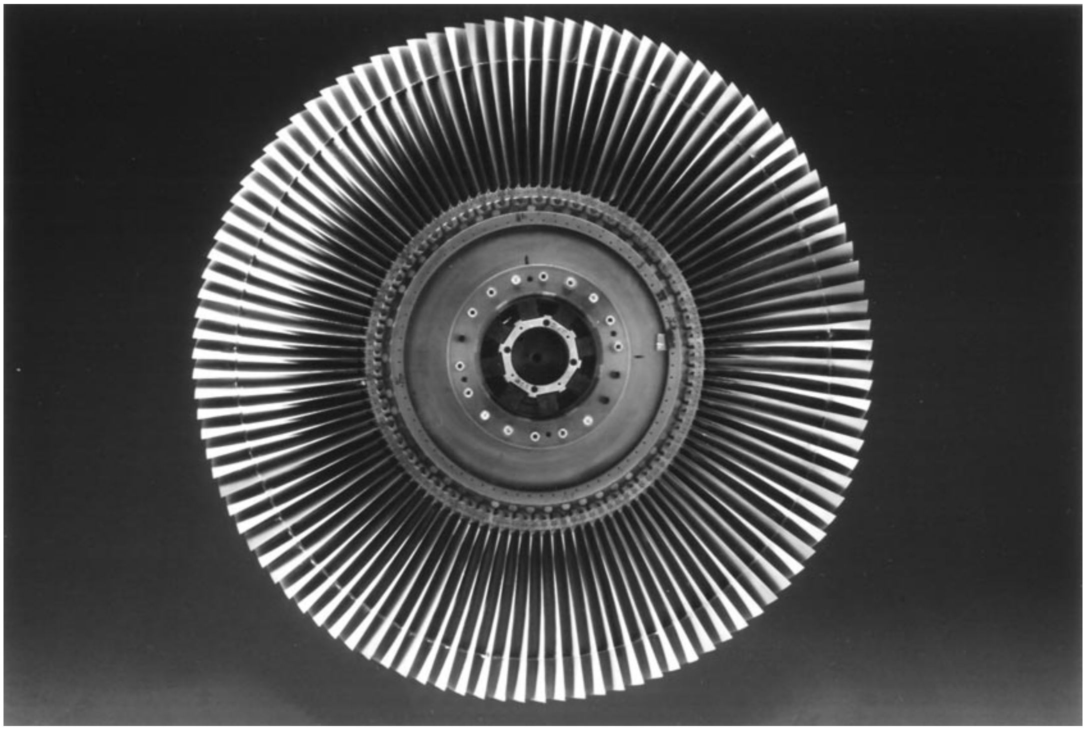


Figure 3.—106 bladed fan rotor.

Figure 4.—14 vane stator assembly.

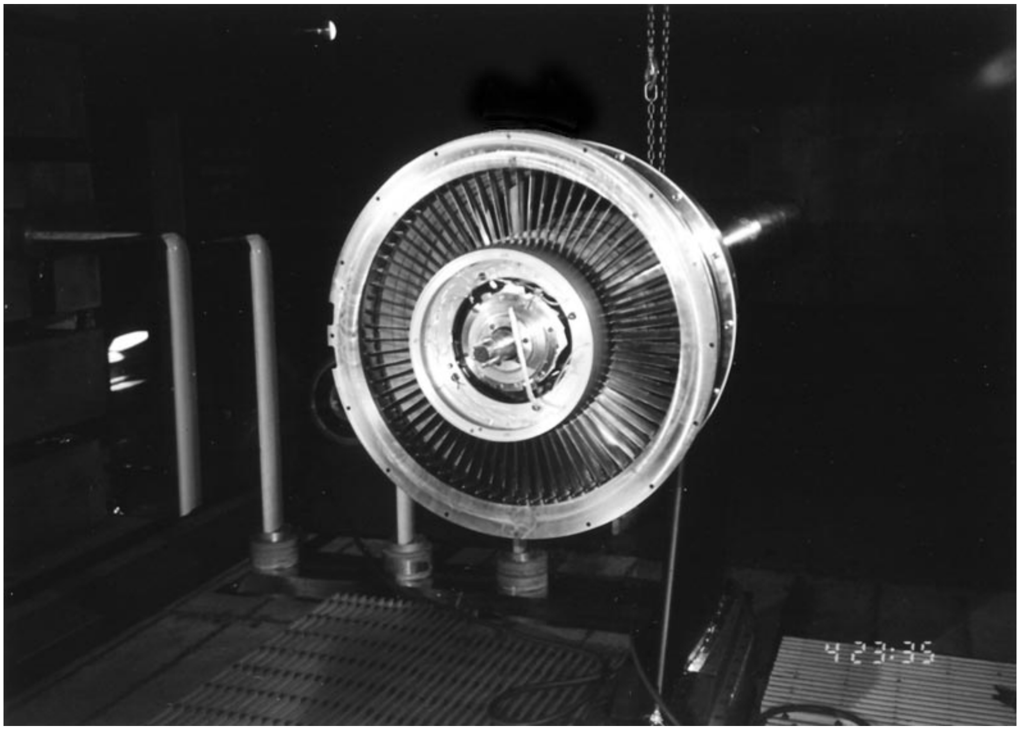


Figure 5.—70 vane stator assembly.

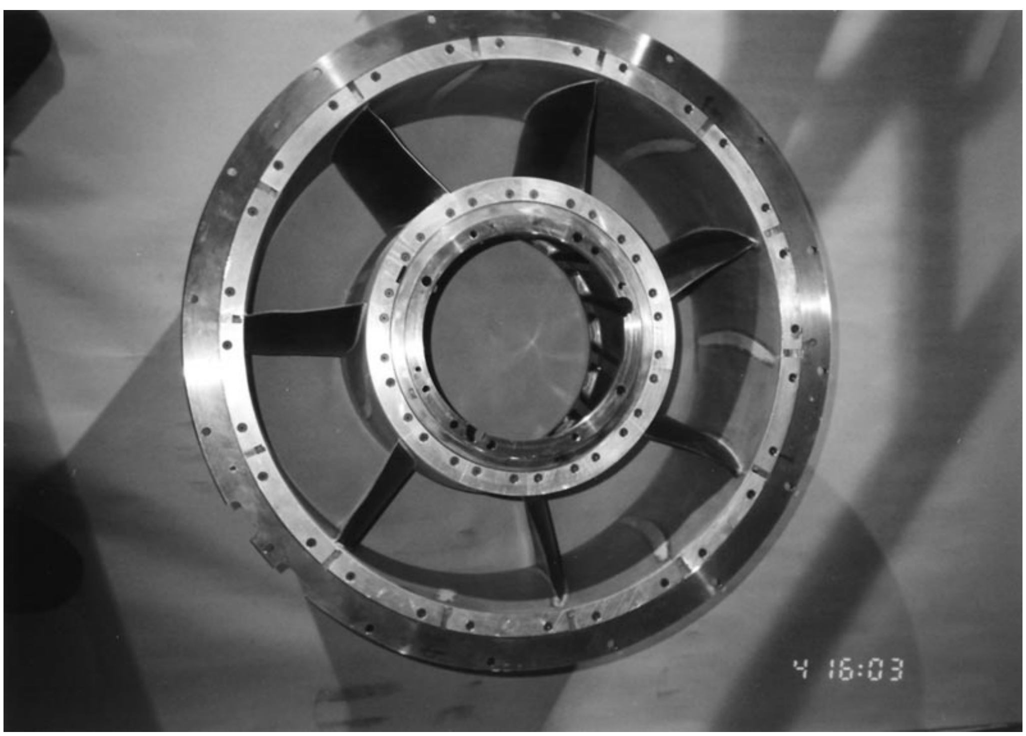


Figure 6.—7 vane stator assembly.

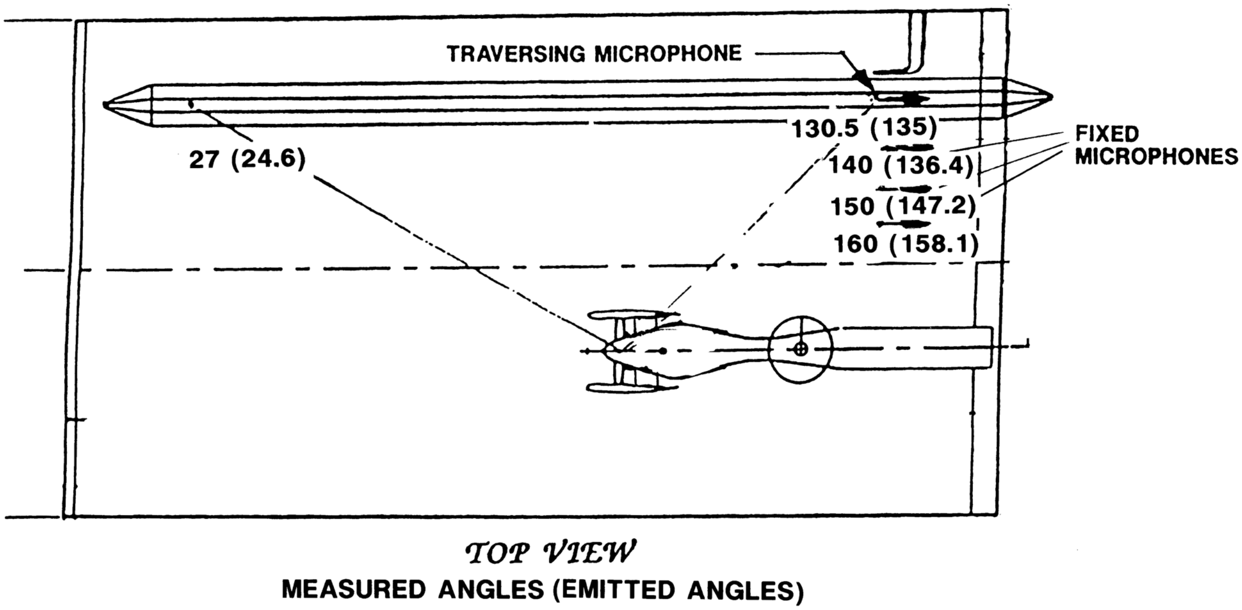


Figure 7.—Model in 9x15 test section.

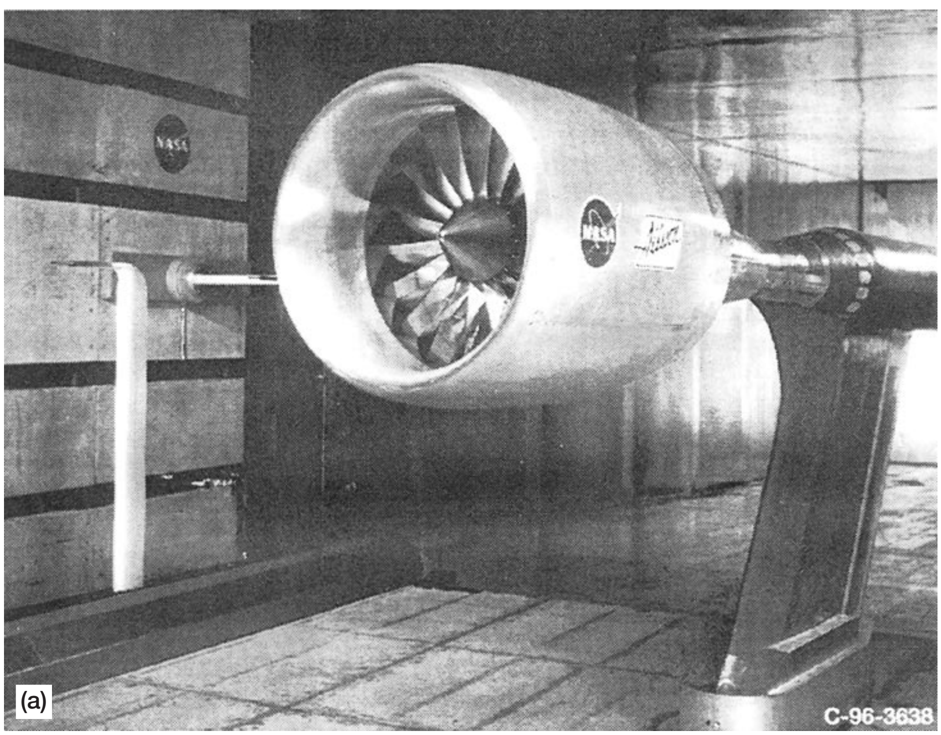
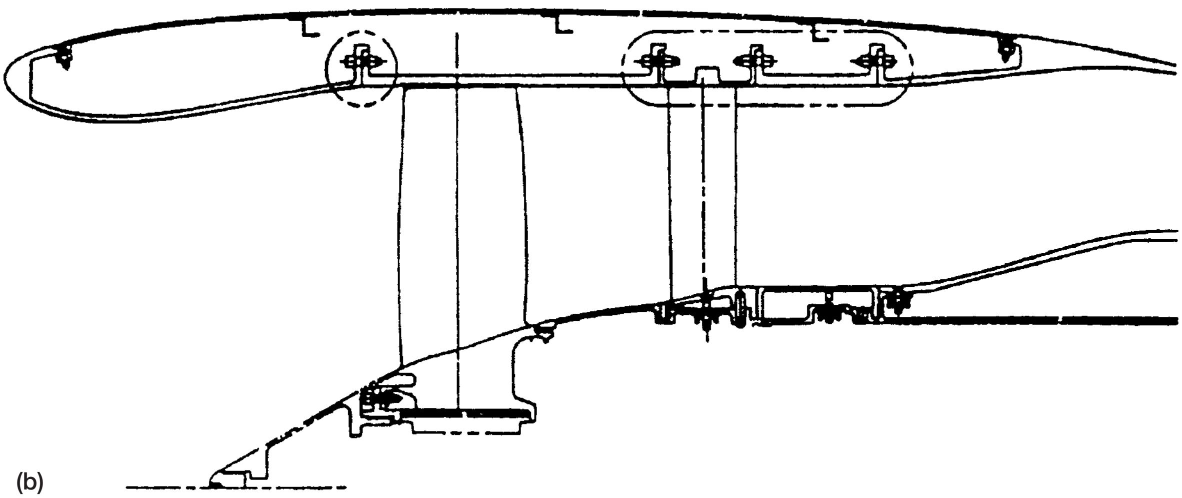


Figure 8.—Allison fan. (a) Photograph in wind tunnel. (b) Cross section.



(b)

Figure 8.—Concluded. (b) Cross section.

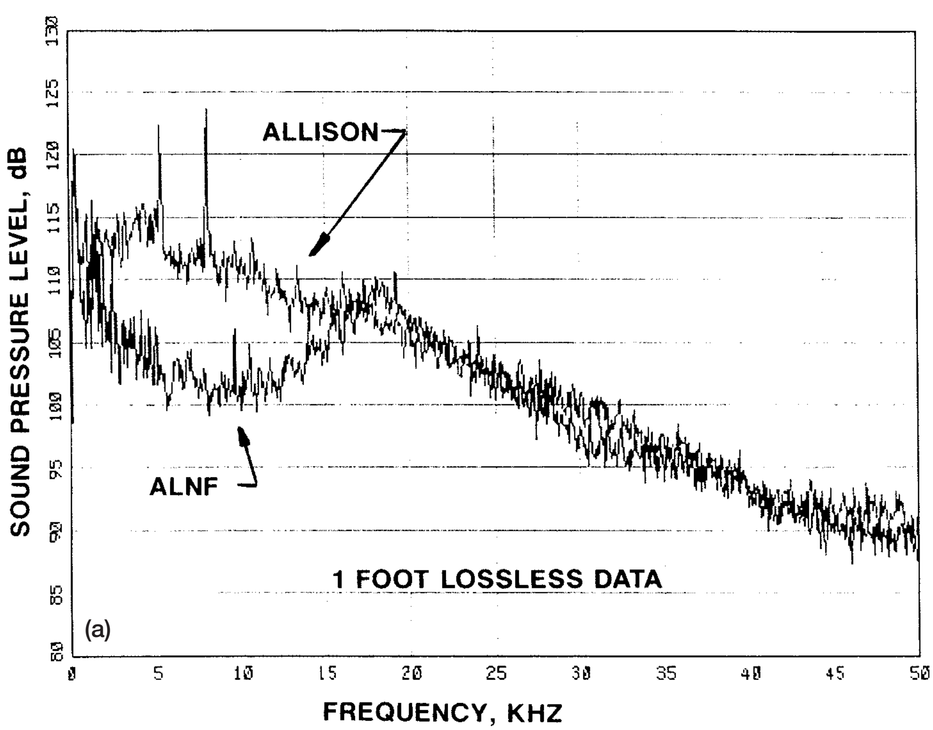


Figure 9.—Narrowband noise data. Nominal takeoff, Allison 840 ft/sec, ALNF 1000 ft/sec. (a) 25° emitted angle. (b) 90° emitted angle. (c) 128° emitted angle.

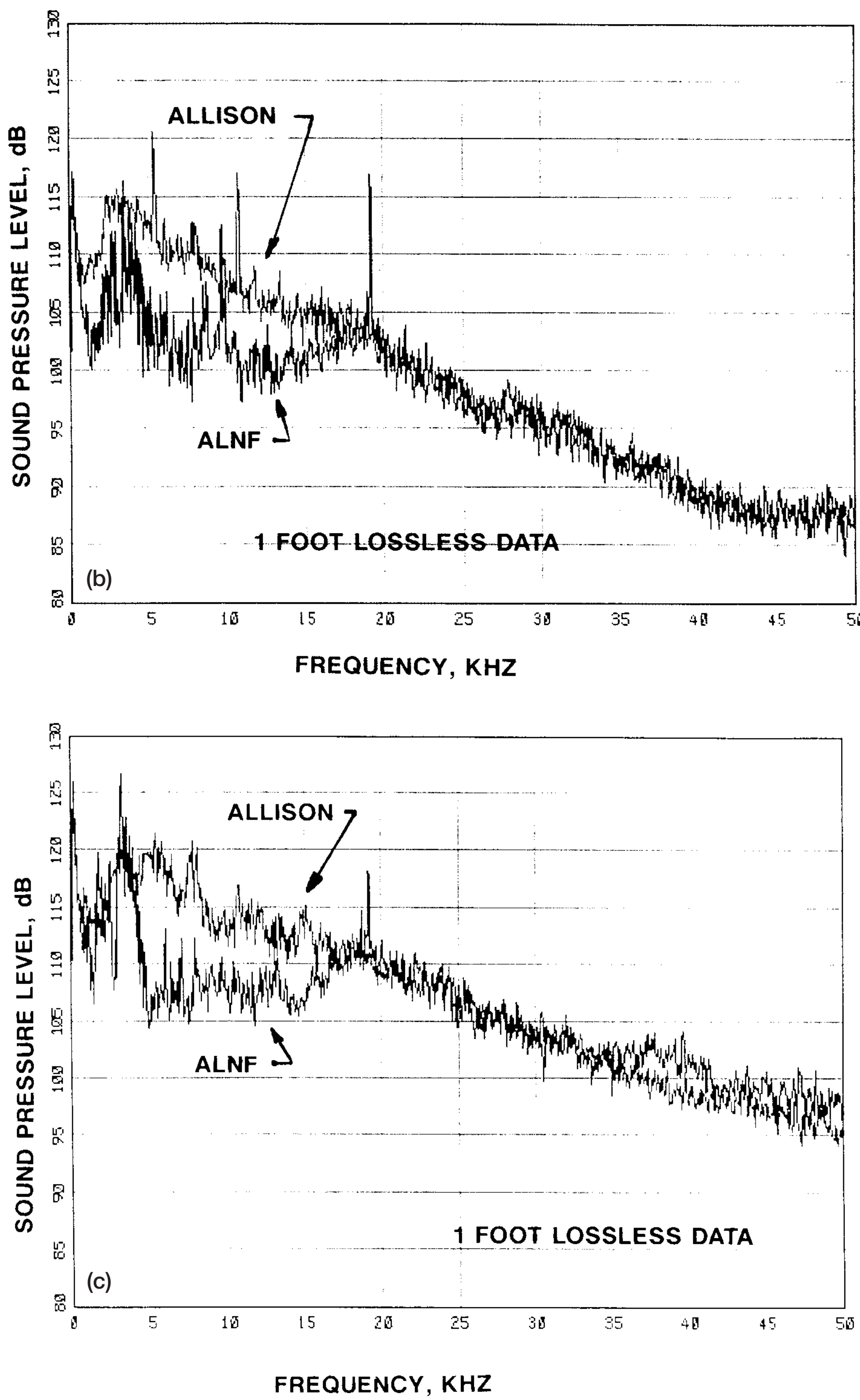


Figure 9.—Concluded. (b) 90° emitted angle. (c) 128° emitted angle.

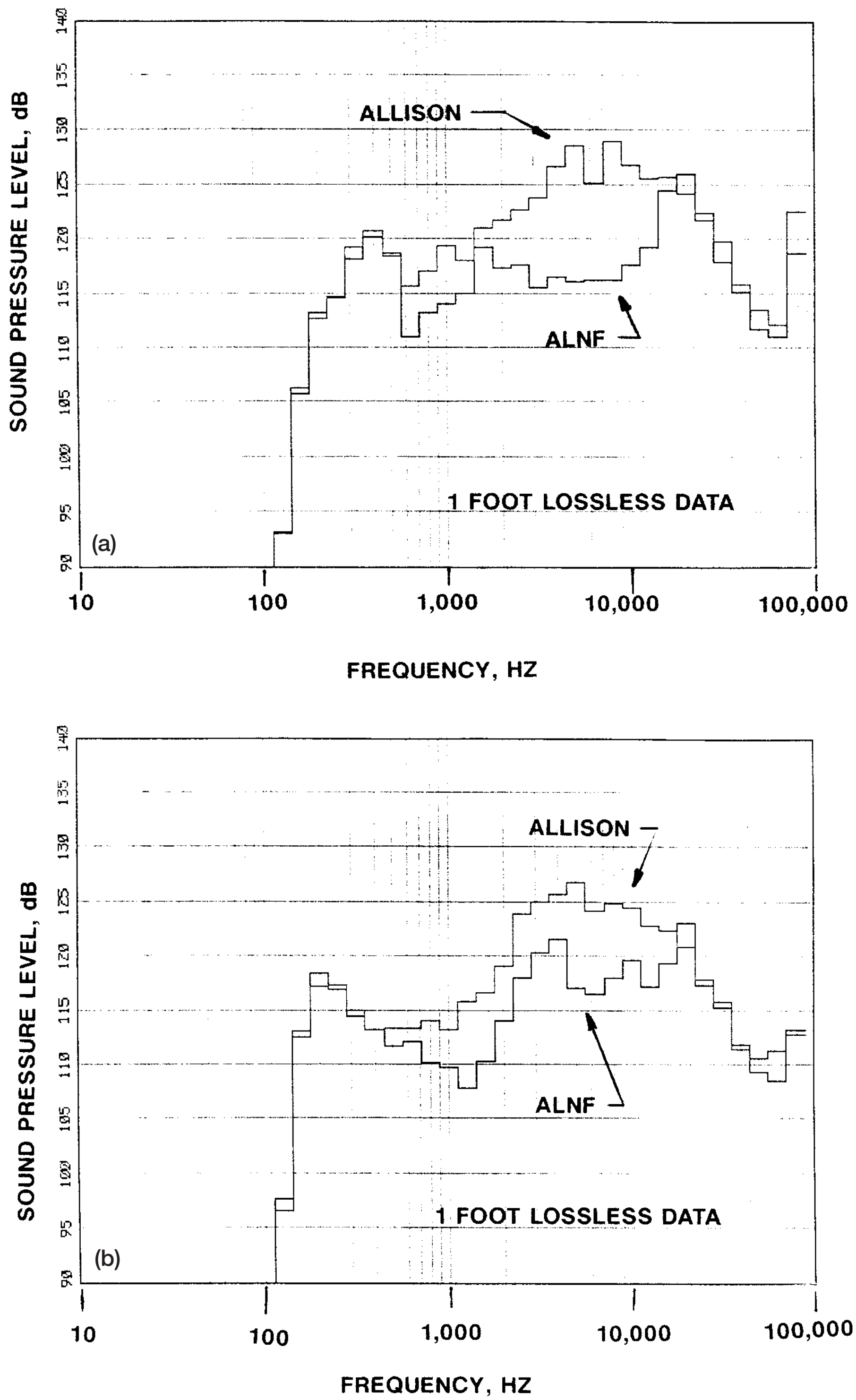


Figure 10.—1/3 octave noise data. Nominal takeoff, Allison 840 ft/sec, ALNF 1000 ft/sec. (a) 25° emitted angle. (b) 90° emitted angle. (c) 128° emitted angle.

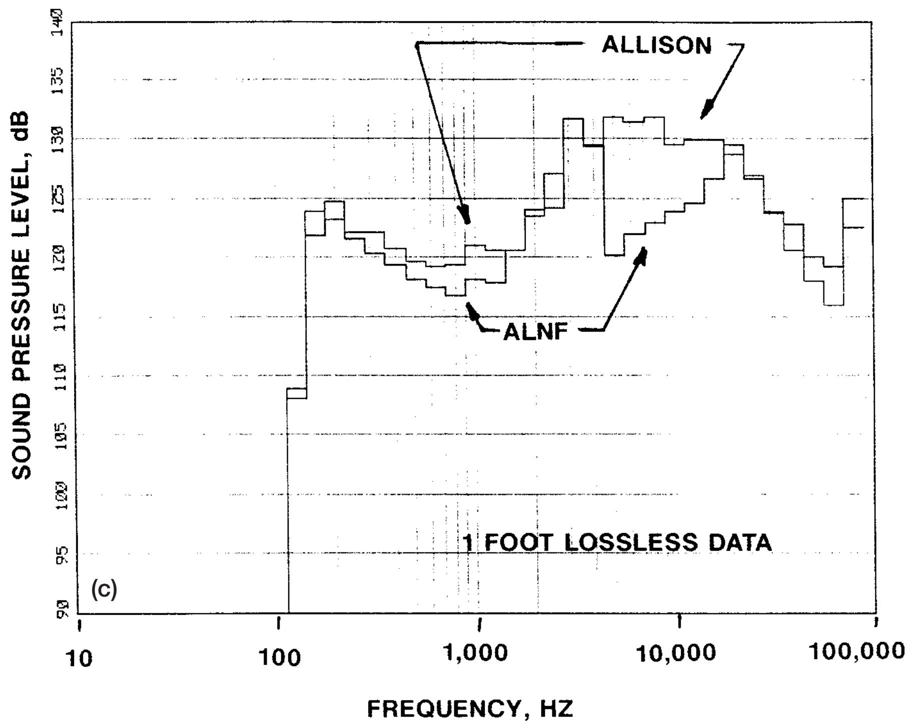


Figure 10.—Concluded. (c) 128° emitted angle.

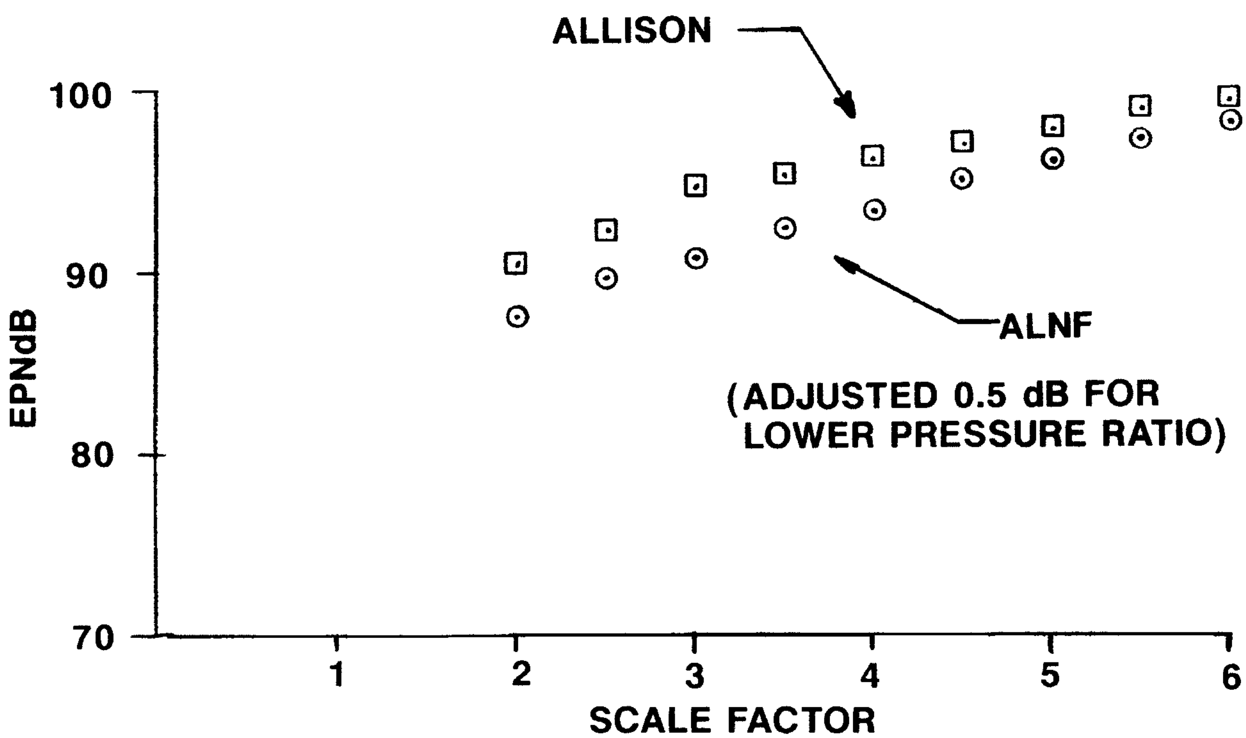


Figure 11.—Flyover noise at 1000 ft, standard day.

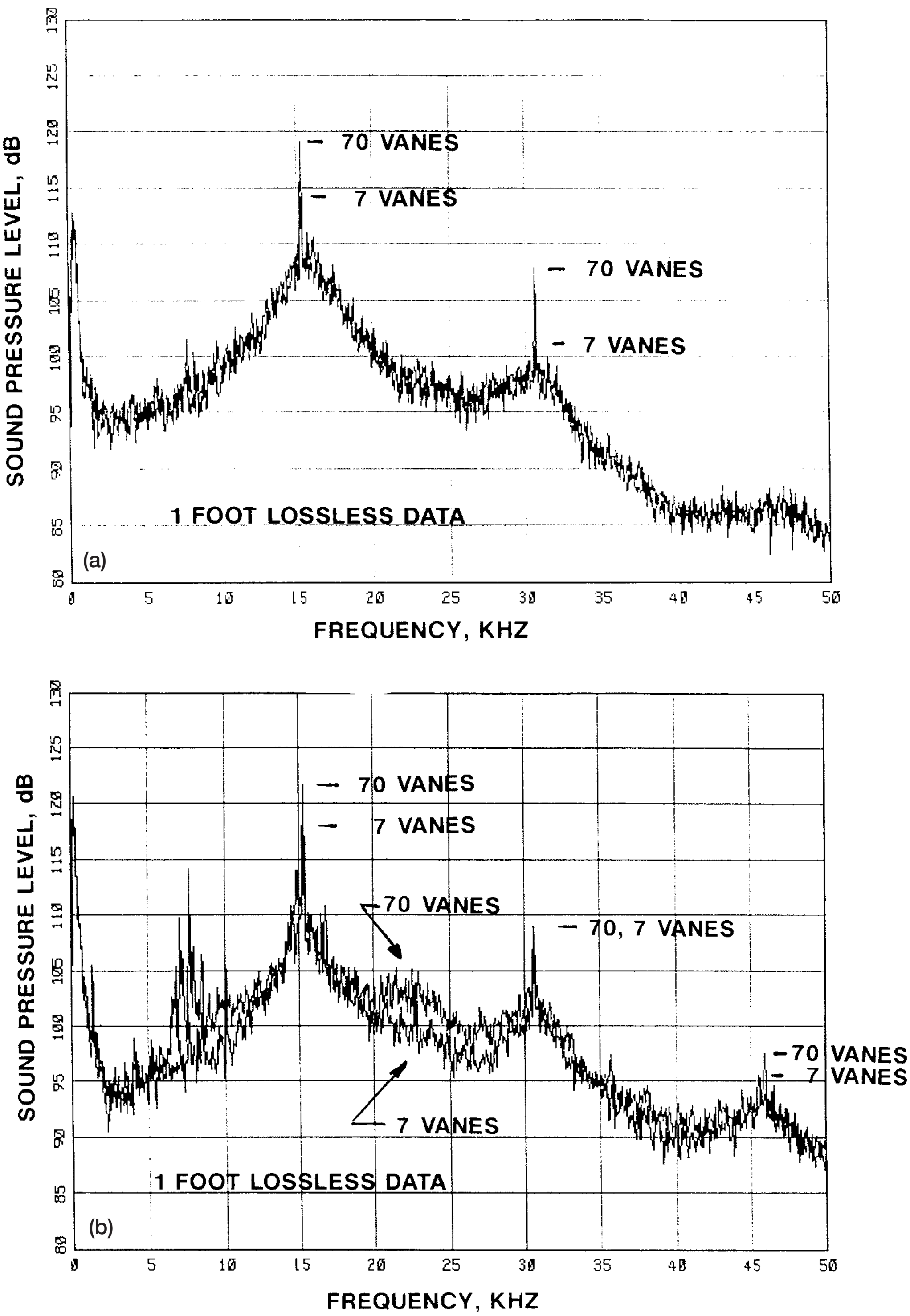


Figure 12.—Narrowband noise data. ALNF at 800 ft/sec tip speed. (a) 25° emitted angle. (b) 128° emitted angle.

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13. ABSTRACT ***(Maximum 200 words)***

The use of low tip speed, high bypass ratio fans is a method for reducing the noise of turbofan jet engines. These fans typically have a low number of rotor blades and a number of stator vanes sufficient to achieve cut-off of the blade passing tone. Their perceived noise levels are typically dominated by broadband noise caused by the rotor wake turbulence - stator interaction mechanism. A 106 bladed, 1100 ft/sec takeoff tip speed fan, the Alternative Low Noise Fan, has been tested and shown to have reduced broadband noise. This reduced noise is believed to be the result of the high rotor blade number. Although this fan with 106 blades would not be practical with materials as they exist today, a fan with 50 or so blades could be practically realized. A noise estimate has indicated that such a 50 bladed, low tip speed fan could be 2 to 3 EPNdB quieter than an 18 bladed fan. If achieved, this level of noise reduction would be significant and points to the use of a high blade number, low tip speed fan as a possible configuration for reduced fan noise.

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